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Integrating mission, robot localization and communication requirements through collaboration

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Technical Section

Objective

To develop a de-centralized system for allocating mobile sensor assets controlled by teams of autonomous air vehicles (AVs) and deployed in spatially complex urban environments. The sensor assets are to support AV missions involving the pursuit of one or more mobile intelligent ground adversaries. Since sensor information is typically uncertain and incomplete, AVs must be able to cooperate to coordinate sensor assignments in the most efficient way possible. The environments in which such teams are deployed are spatially complex, introducing additional uncertainty arising from perceptual occlusions and the like. In addition to target tracking, we also plan to develop distributed algorithms for dynamically clustering vehicles around objects of interest (e.g., to protect a convoy). Existing approaches to coordinating the activities of AVs have focused on essentially 2D environments.

(NB: The focus of this effort has been changed somewhat as a result of guidance from the previous ONR Program Manager, Dr. Allen Moshfegh. A more appropriate title for this research might be: Distributed allocation of autonomous air vehicles in pursuit of intelligent adversaries in complex urban environments.)

Approach

Our approach is divided into three areas of work:

1. **Spatial representation and reasoning, including path planning.** Space is discretized into a distribution of AV configurations and projections of adversaries over time are computed. We make use of 3d data obtained for an urban environment from Planet 9 Studios. The data is geo-referenced using SRI geo-VRML.
2. **Rich simulation environment for experimentation.** We have developed an OpenSim simulation environment in which alternative initial resource and target arrangements can be defined and in which computed flight paths can be displayed during resource allocation.
3. **Distributed algorithm design and experimentation for solving the AV collaboration problem.** We are exploring and experimenting with several different approaches to this problem. Our first made use of an auction mechanism for task allocation and demonstrated very interesting emergent behavior (discussed in more detail below). However, we found that a purely auction-based system for allocating the best resource at each round may lead to a bad solution: for instance, the choice of the first best resource can make the last resource impossible to allocate. To address this problem, we are developing a second approach, which we plan to experimentally compare with the auctioning approach. The second approach is a probabilistic one, that handles the potential state space explosion characteristic of conventional MDP-based approaches. We apply simulated annealing to the problem of minimizing cost and maximizing utility within a group of heterogeneous resources.

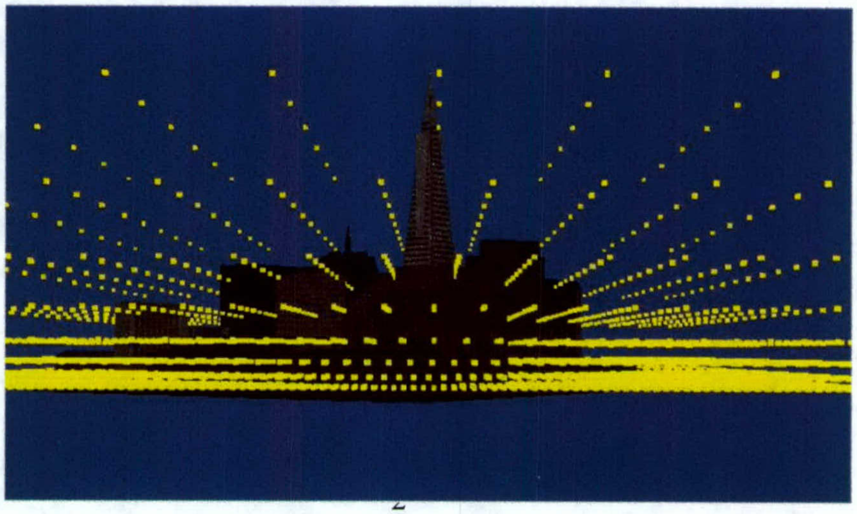
Progress

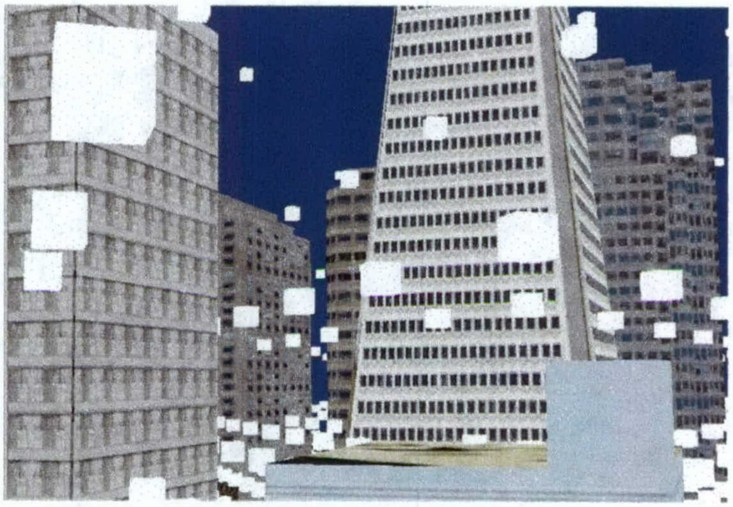
The start date of this project was 6 August 2003. The following summarizes our progress relative to the three tasks described above.

1. **Spatial representation and reasoning, including path planning.** We are working with models of cluttered urban environments that look like the following (showing downtown San Francisco).

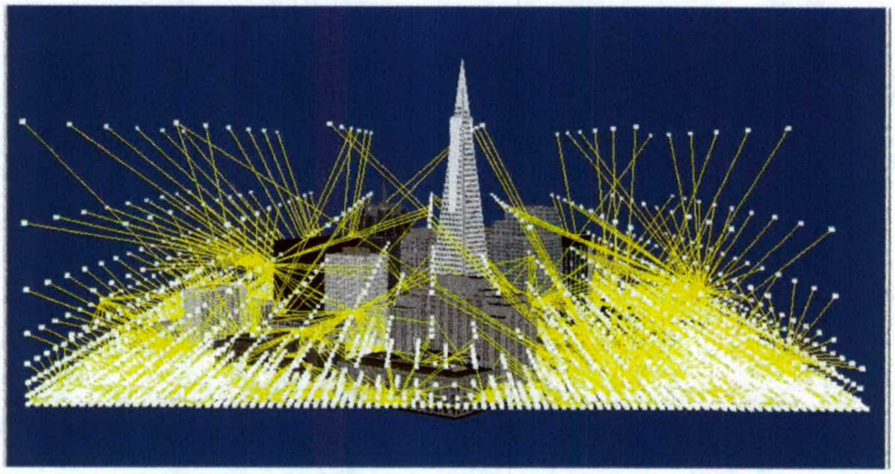
The size of the "world" that we are working from is 567 x 595 meters (altitude = 269 meters). The space is discretized in a regular distribution of configurations (roadmap). A configuration is a valid position in the space for a UAV.

We generate 1237 collision-free configurations in less than one second in computing a "roadmap" of navigatable paths. We make use of an irregular distribution of cubes to discretize the space: the intuition is that there is more clutter the lower one is to the ground. This step is shown in the figures below.





Next, we compute a spanning tree. An edge is added between two configurations, c1 and c2, in the spanning tree, only if a local path is found between c1 and c2 (using a local path planner). This results in one component with approximately 12372 edges. Computation time is approximately 20 seconds. The following figure shows the resulting spanning tree.



The final step involves the path planning. Path planning between two positions P1 and P2 involving:

- Connection of P1 and P2 to the roadmap (local planning giving the closest reachable configurations c1 and c2)
- Path planning between c1 and c2 (A*) in the roadmap
- Path optimization (smoothing)

The computation time per path is a few seconds. The results are shown in the following figure.

2. **Rich simulation environment for experimentation.** We have developed a simulation environment for testing and displaying experiments in such 3D environments. Movies of the simulation in action, showing the two approaches explored so far and discussed in (3) below, are available at our project website.

3. **Distributed algorithm design and experimentation for solving the AV collaboration problem.** In the *auction-based approach,* a set of valid visibility points (VVP) are computed. Vehicle Vi reaching a valid point of visibility with the smallest existing time is picked. Vi is then removed from the vehicle list. Points inside the "chasing distance" are removed from VVP. A coordinator/auctioneer can be chosen dynamically and announces the set of future time points that need to be covered. From one simple negotiation protocol, 3 unique behaviors (handoff, tracking and helping) emerge. In the probabilistic approach a projection module first generates the evolution of the environment over time. Example: for the tracking task, the possible moves for the evader over the next 2 minutes. For a convoy protection mission, the possible moves are of the convoy and the enemies. Time is then discretized into quanta. Each configuration is labeled by a set of probabilities Pi. For a configuration C, Pi gives the probability for a positive event (evader presence, convoy presence) at t = i. Now that each configuration of the space is labeled with a distribution of probabilities over the time, we want to find the best resource allocation:

   a. to maximize the positive events (Pi)

b. to minimize a Cost function (ex : fuel used, redundancy with the other allocations, shield porosity etc ...)

c. to maximize a Utility function (ex : quality of observation, communication link etc ...).

Each task has a specific cost and utility function. This optimization is done over n quanta of time by using Simulated Annealing. Once the computation is done (over n quanta), the allocations for $t = 1$ are performed by the UAVs. The environment is modified. A new projection is computed and a new allocation is computed again.

Cumulative Statistics

Journal publications

None.

Conference presentations/proceedings

1. "Distributed Robotic Systems in Cluttered Urban Environments, " Symposium on Bridging the Multiagent and Multirobotic Research Gap, Stanford University, Spring 2004.

2. "Distributed allocation of autonomous air vehicles in pursuit of intelligent adversaries in complex urban environments," (to appear, 2004), book chapter, Adversarial Reasoning edited by Alex Kott.

3. "Spatial Reasoning for Very Large Scale Robotic Swarms in Urban Settings," 2nd Annual Swarming: Network Enabled C4ISR Conference, June 2004.

Invention disclosures/patents

None.

Awards or other noteworthy recognition

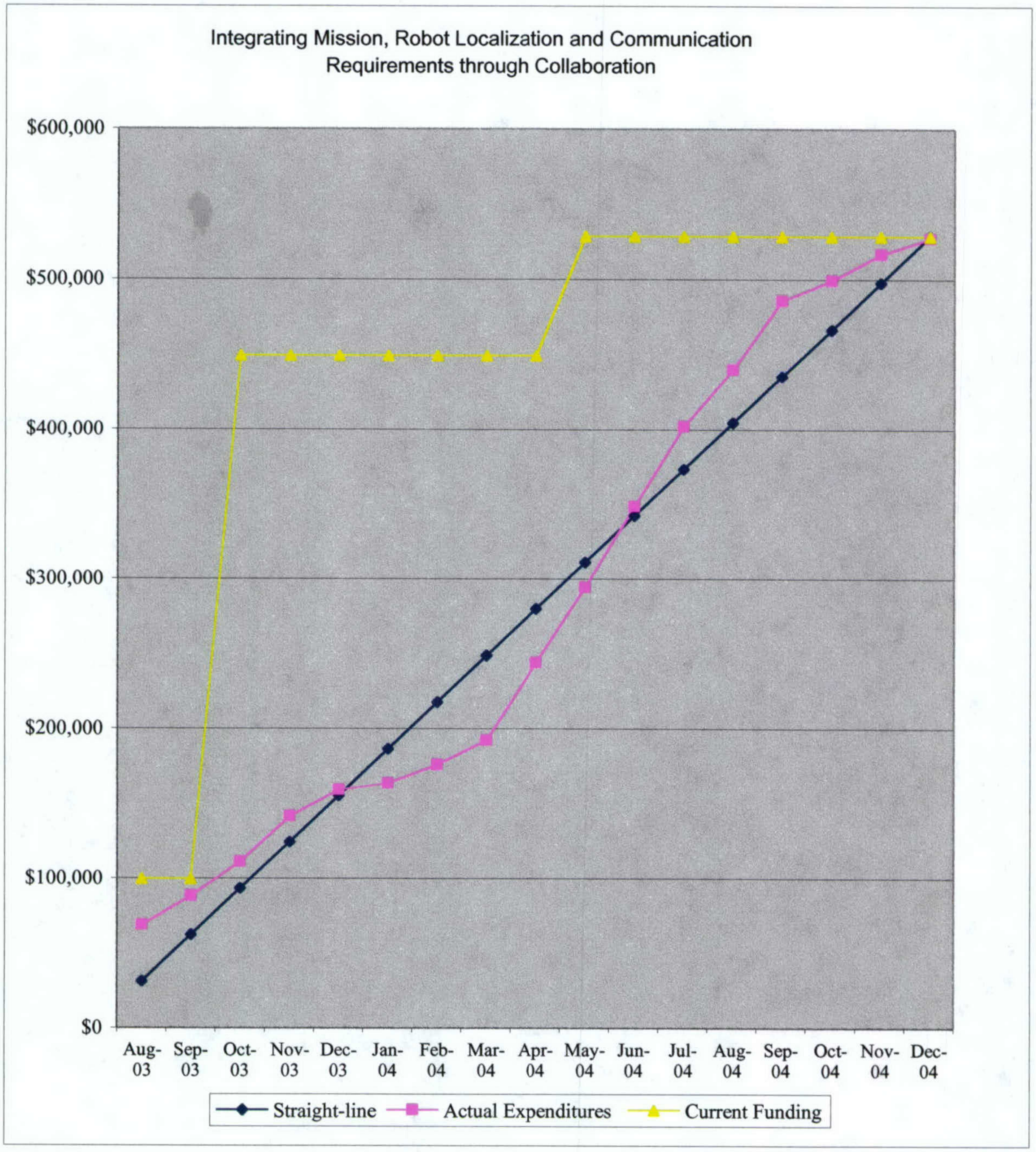
None.

Students/Postdocs supported by this grant

Dr. Benoit Morisset was supported as a postdoc.

Financial Status

Financial Status Report Inception through December 31, 2004				
	Current Period		Cummulative	
	Labor Hrs.	Labor $	Labor Hrs.	Labor $
Labor	124	$33,835	3031	$418,859
Other Direct Costs				
Materials and Supplies				$6,081
Outside Services				$1,046
Internal Computing		$2,472		$41,506
Shipping & Receiving				$2,374
Subscription and Books				$8,430
Meal Expenses		$1,005		$6,392
Travel Expenses		$4,039		$42,702
Telephone Tolls		$22		$304
Total Other Direct Costs		$7,538		$108,835
Total Project Expenses		$41,373		$527,694
Project Commitments				
Total Expenses				$527,694


Integrating Mission, Robot Localization and Communication
Requirements through Collaboration
$600,000
$500,000
$400,000
$300,000
$200,000
$100,000
$0
Aug-03
Sep-03
Oct-03
Nov-03
Dec-03
Jan-04
Feb-04
Mar-04
Apr-04
May-04
Jun-04
Jul-04
Aug-04
Sep-04
Oct-04
Nov-04
Dec-04
Straight-line
Actual Expenditures
Current Funding